# APPENDIX A

## REASONABLE WORST CASE ANALYSIS
## DIRECT INJURY TO BENTHOS

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# STAGE 1: Injury through December 31, 1999

## 1.0 INTRODUCTION

The injury assessment for benthos is being addressed in two, time-defined phases. This technical memorandum summarizes Stage 1 of that injury assessment, which addresses the interim losses of benthos functions or services due to exposure to hazardous substances released from the Alcoa facility and response activities undertaken at the Alcoa (Point Comfort)/Lavaca Bay NPL Site (the Site) through December 31, 1999.

The injury assessment for benthos is being phased to accommodate present uncertainty about future response actions at the Site. The effect of all response actions must be taken into account to complete the assessment of benthos injuries. Certain response actions, i.e., removal actions and treatability studies - have already been undertaken and are either presently complete or are of well defined scope. The impact of these actions on benthos can be evaluated based on available information, however, it is not known at this time what, if any, further response actions will be required at the Site as part of the final remedial decision. EPA's Record of Decision has not yet been released and it is not known when that decision will be made. The Trustees are phasing the injury assessment in order to expedite the identification of restoration-based compensation for benthos injuries based on the information that is currently available. Assessment and compensation determinations for the balance of the interim benthos losses will be covered in Stage 2, when the nature and scope of any further injuries to benthos from the final remedy decision and the extent of future benthic losses can be determined. The Stage 1 assessment addresses losses of benthos function and services from December 1980, including those attributable to injuries beginning before and continuing after that date as well as those attributable to injuries occurring after December 1980. The Stage 1 assessment encompasses these losses through December 31, 1999.

Benthos is a broad term that describes the aquatic invertebrate organisms living on or in the sediments in an aquatic ecosystem. Benthic organisms are found in and on bottom and oyster reef habitats in Lavaca Bay. Benthic organisms often feed on organic detritus that is mixed with the top few centimeters of sediment or is trapped in the silty fines that cover the sediment surface. Most other trophic niches (herbivores, predators, scavengers, etc.) are also represented in the benthic community. Benthic communities utilize sediment-bound nutrients and organic substances that are not generally available to epiphytic or pelagic organisms and therefore provide an important part of the overall food web within an estuary. The types of services that are provided by benthos that can be affected by site contaminants include the following:

- **Food and Production:** Benthic populations include both meiofauna and macrofauna that are classified into groups based on their relationship with the sediments. These relationships include either burrowing (infaunal), deposit feeders or epibenthic species. Benthic organisms are generally fast growing, adaptable and serve as an important basal component of the baywide food web. Infaunal and epibenthic organisms utilize nutritional resources that are not available to larger organisms (i.e. bacteria, algae, and partially decomposed organic detritus). Benthic organisms serve as an important source of food for fish, crabs and shrimp that use the bays. By providing the nutritional base for the developing stages of many finfish and shellfish, benthos production affects all trophic levels in the bay system.

Many species of small deposit feeding annelid worms, mollusks and amphipods live in surficial sediments without burrows. The worm populations feed on organic detritus that includes bacteria and other microscopic decomposers. Populations of polychaete worms grow rapidly when bay waters warm and serve as one of the primary sources of food for juvenile shrimp and crabs. Juvenile shrimp and crabs enter the estuary and feed on worms, dramatically reducing polychaete worm populations. The shrimp and crabs are prey items for spotted seatrout, sand trout, red drum, southern flounder, gafftopsail catfish, lizardfish, birds and other organisms.

Burrowing benthos includes lug worms, parchment worms, tube worms, bivalves, amphipods, shrimp eels, worm eels and mudshrimp. In permanently submerged habitats (open water) finfish predators like spot, pinfish, and Atlantic croaker feed on the burrowing benthos. These finfish are prey items for larger predators like spotted seatrout, red drum, black drum and southern flounder. In shallow water or on exposed mud flats, wading birds (i.e., willets, long-billed dowitchers, long-billed curlews, and black-necked stilts) feed on the burrowing worms and amphipods.

Epibenthic species include animals such as juvenile blue crabs, mud crabs, stone crabs, penaeid shrimp, mysids, copepods, and non-burrowing polychaete worms. Epibenthic species tend to be more mobile and feed on epiphytic algae and surficial detritus. The small crabs use their chelipeds to crush and eat oyster spat, barnacles, limpets, and mussels that are generally attached to hard substrate. The adult shrimp, mysids, and copepods feed primarily on algae and surficial detritus.

– **Conditioning & Improvement of Habitat:** The benthic ecosystem includes a variety of habitat types in and on sand, mud, and shell bay bottoms. Many infaunal species live in burrows and filter their food from water that is circulated through the burrow. Sediment excavated from the burrows is deposited on the sediment surface at the burrow opening. Water circulated through the burrows helps to oxygenate deeper sediments allowing other organisms and aerobic bacteria to inhabit deeper sediment layers. In addition, the excavation of sediment re-introduces nutrient-rich deep sediment to the surface where it can be utilized by grazers and deposit feeders.

– **Decomposition and Nutrient Cycling:** A complex community of bacteria, meiofauna and macrofauna exists within the sediments and contributes to the reduction and decomposition of organic matter and debris. The process of decomposition is important for the cycling of carbon and nutrients back through the aquatic food web.

To summarize, the benthic community provides important ecological services primarily related to food production, decomposition and energy cycling. These services are related to the productivity of the system and affect nearly all organisms within an estuarine system. A potential adverse impact on benthic populations has the potential to impact biota in all trophic levels of the bay system by reducing the overall productivity of the system.

## 2.0 DATA

The potential for interim loss from exposure to hazardous substances from the Alcoa Point Comfort Operations (PCO) facility was determined both directly and indirectly through studies conducted to assess injury to benthic habitat within Lavaca Bay. Analytical chemistry data were collected during the remedial investigation on the nature and extent of polylchlorinated biphenyls (PCB), mercury (Hg), and polynuclear aromatic hydrocarbons (PAH) contamination in Lavaca Bay sediments. The scientific literature on the potential effects of the contaminants was examined and compared to site analytical chemistry data. Laboratory bioassays and benthic macroinvertebrate studies were conducted to determine whether any relationship exists between mercury concentrations in surficial sediments and observed effects on survival, growth and reproduction endpoints for benthic populations within Lavaca Bay. Benthic surveys /bioassays were not conducted in areas with PAH contamination in sediment, thus, any conclusion regarding the potential injury to benthos from PAH was based on a comparison of the Site data to results of studies conducted at other locations with similar contaminants. Low levels of PCB contamination were irregularly distributed in bay sediment. Sediment PCB concentrations were compared to ecological effects benchmarks to determine the potential for injury to benthos.

The assessment process used supporting information from the remedial investigation of Lavaca Bay. This information included analytical data collected in the remedial investigation that documents the nature and extent of contamination in sediments in or near existing benthic habitats, results from the sediment quality triad study (SQT) conducted to assess a relationship between the concentration of mercury in sediments, the toxicity as measured in standard laboratory bioassessment tests and observed changes in benthic macroinvertebrate populations in Lavaca Bay sediments. Information from the scientific literature that documents the adverse effects of PAHs and PCBs on growth, survival and reproduction of benthic populations was also utilized.

Specific information used to quantify potential injury in this analysis includes:

- Sediment samples collected for the Remedial Investigation (RI), to include results from the Stage 2A (RI Report Volume B2b), 2B (RI Report Volume B2a), and Mercury Reconnaissance Study (RI Report Volume B2c), as well as supplemental data collected under Workplan Refinement Notices B2b-RN06 through B2b-RN09 that present the nature and extent of contamination in Lavaca Bay;
- Supplemental PAH sampling conducted in the open water areas of Lavaca Bay to the southwest of Dredge Island;
- Sediment sampling results for oyster reefs, fringe marshes and open water areas from the Prey Item Study (RI Report Volume B2e);
- Sediment, bioassay and benthic macroinvertebrate results from the Sediment Quality Triad (SQT) study (RI Report Volume B2g);
- Sediment sample results from the Radiochemistry program (RI Report Volume B3a);
- Habitat Mapping that identifies the location of specific habitats important for benthos, including open water areas, fringe marsh/inter-tidal zones, and oyster reefs.
- A site specific delineation of oyster reefs in the area of potential injury
- Literature-derived benchmark concentrations on the toxicity of chemicals to sediment benthos.

## 3.0 ANALYSIS PROCEDURES

Potential injuries and interim losses to benthos were assessed following a reasonable worst-case (RWC) approach primarily using existing data sources from the remedial investigation and information from the scientific literature. Estimates of interim benthos service losses were developed based on an evaluation of direct toxicity to benthic organisms from polynuclear aromatic hydrocarbons (PAHs), mercury and polychlorinated biphenyls (PCBs).

Injury estimates for PCBs, PAHs and mercury were quantified using a RWC approach based on the following procedures:

- For each chemical, contamination benchmarks were identified that are known or suspected injury thresholds for benthic resources. Benchmark concentrations for PCBs, mercury and PAHs were derived primarily from a number of different literature-based sources. The benchmarks were then used in a weight of evidence fashion to identify concentration ranges that result in an increasing severity of injury associated with the chemicals present in the sediment.

- Habitats where sediment concentrations exceeded benchmark concentration ranges were mapped. The areal extent of co-occurring contaminants (mercury and PAHs) was also mapped for each habitat type. The specific sediment data used included analytical data collected in support of the Remedial Investigation as well as focused PAH sampling in support of NRDA. Separate estimates were prepared for oyster reef habitats, fringe marshes (with contiguous mudflats), and open water areas;
- Potential sediment effects from mercury were evaluated directly in the open water area using a Sediment Quality Triad (SQT) study. Because the Sediment Quality Triad study did not evaluate all potential endpoints for benthos, the RWC analysis relied primarily on literature-based criteria. The selection of the appropriate benchmarks used in the analysis, and the percent loss of services for the injury associated with these concentrations, was influenced by the findings of the Sediment Quality Triad study, however.
- For each concentration range, the reduction in ecological services provided by the benthic community in each habitat type was estimated as a percent loss of services. Percent loss of service estimates were derived based on the weight of evidence using results of the mercury SQT, available scientific literature, and knowledge of Texas estuarine ecosystems.

## 3.1 SELECTION OF INJURY THRESHOLD CONCENTRATIONS

For the benthos RWC assessment, ecological risk screening sediment benchmarks were selected and used as thresholds for varying levels of injury to benthic resources. Generally three screening values were used in this assessment, the Effects Range-Low (ER-L), the Effects Range-Median (ER-M) and the Apparent Effects Thresholds (AET). These benchmarks are used in ecological risk assessments to screen for the potential for effects to benthic organisms. The ER-L is calculated as the lower $10^{th}$ percentile concentration of the Biological Effects Database (available sediment toxicity data) that has been screened for only those samples which were identified as toxic by the original investigators. The ER-L is not the concentration that is toxic to 10 percent of the test organisms ($LC_{10}$). The ER-L is at the low end of a range of levels at which effects were observed in the studies examined. It represents the value at which toxicity may begin to be observed in sensitive species. The ER-M is simply the median concentration of only samples labeled as toxic by the original investigators. The ER-M is not an $LC_{50}$. Other benchmarks were considered for PCBs, specifically "consensus values" developed for the Grand Calumet River and the Hudson River. These benchmarks were developed in a similar manner as the ER-L and ER-M and are intended as screening guidelines for freshwater systems. These benchmarks were included for comparative purposes.

Apparent Effects Thresholds (AETs) were developed for use in Puget Sound to relate chemical concentrations in sediments to at least one of five biological indicators of injury (i.e., four sediment bioassays or diminished benthic infaunal abundance.) AETs are essentially equivalent to the concentration observed in the highest non-toxic sample. As such, AETs represent the concentration above which adverse biological impacts would always be expected in that biological indicator due to exposure to that contaminant alone.

### 3.1.1 Mercury

Sediment benchmarks used in the consideration of potential injury to benthos due to releases of mercury include:

- Effects Range-Low (ER-L) of 0.15 mg/kg from Long *et al.* (1995);
- Effects Range-Median (ER-M) of 0.71 mg/kg from Long *et al.* (1995);
- Puget Sound amphipod (and overall benthos) AET of 2.1 mg/kg (State of Washington, 1995);
- Puget Sound oyster larvae AET of 0.59 mg/kg (State of Washington, 1995);

The Sediment Quality Triad (SQT) study performed for mercury excluded co-located PAH contamination so that mercury effects alone could be determined. The study found no measurable effect on endpoints measured in bioassays (reduction in growth and survival of *Neanthes spp.*, or survival in *Leptocheirus spp.*) along a sediment mercury gradient of concentrations (from 0.3 mg/kg to 4.6 mg/kg). No measurable effects on indices related to benthic macroinvertebrate community abundance or richness were observed.

However, the Trustees recognized that the SQT study did not address all endpoints associated with potential service losses related to benthic exposure to mercury. The sediment quality benchmark concentrations selected as injury thresholds for the RWC analysis were identified in a review of the open literature to conservatively account for potential injury associated with endpoints not studied in the SQT. Additionally, quantification of injury was based on existing (rather than historical) mercury and PAH distributions in sediment, determined from Stage 2A and 2B Remedial Investigation studies, further supporting the use of conservative benthos injury thresholds.

Injury thresholds were established at the ER-M and AET levels. The SQT results suggest that the ER-L value of 0.15 mg/kg is well below levels where injury would be expected to occur, and, therefore, is not an appropriate RWC benchmark value to represent potential injury to the benthic community within Lavaca Bay.

The following benchmark values and concentration ranges were selected for estimating injury from mercury:

- For estimating injury to benthos in open water and intertidal mudflats/fringe marsh habitats, the concentration ranges for mercury are:
    - No injury = sediment concentrations < ER-M (0.71 mg/kg)
    - Possible injury = ER-M < sediment concentrations < benthic AET (2.1 mg/kg);
    - Probable injury = sediment concentrations > benthic AET.
- For oyster reefs, the proposed benchmark concentration is oyster larvae AET and the concentration ranges are:
    - No injury = sediment concentrations < oyster larvae AET (0.59 mg/kg);
    - Probable injury = sediment concentrations > oyster larvae AET.

Figure 1 depicts the locations within Lavaca Bay where sediment concentrations exceed the ER-M (0.71 mg/kg) and benthic AET (2.1 mg/kg) values in soft bottom, open water and fringe marsh habitats. The "low marsh" habitat from the RI Habitat Mapping study was used to determine acres of fringe marsh habitat. Figure 2 depicts the locations of oyster reef habitat within Lavaca Bay with sediment concentrations exceeding the oyster larvae AET (0.59 mg/kg) for mercury. The acres of bay sediments exceeding mercury benchmark concentrations include:

- Open water habitats:
    - sediment > ER-M: 263.95 acres
    - sediment > Benthic AET: 10.21 acres
- Fringe marsh habitats (with contiguous mud flats):
    - sediment > ER-M: 18.34 acres
    - sediment > Benthic AET: 0.05 acres
- Oyster Reefs:
    - sediment > Oyster Larvae AET: 18.92 acres

### 3.1.2 PAHs

No site-specific benthic-effect studies were performed on sediments from locations with significant PAH contamination. Therefore, the RWC analysis for PAHs did not have the benefit of site-specific studies to quantify potential injury or to evaluate the appropriate literature-based benchmark criteria. The majority of PAH sediment toxicity tests summarized in the literature were based on contaminated sites with complex mixtures of PAHs, namely from coal-tar-based or creosote-based sources of PAHs. PAH contamination in the bay originating from the facility is generally similar to that from coal tar type sources. The open literature was reviewed to identify benchmark criteria based on grouping PAH compounds. Groups considered for this analysis include total PAHs (tPAHs), total low-molecular weight (LPAHs), and total high-molecular weight PAHs (HPAHs), consistent with Long et al. (1995). Relevant sediment benchmarks that were reviewed and considered for evaluating injury to benthos from PAHs on a RWC basis include:

- Effects Range-Low (ER-L) of 4.022 mg/kg for total PAHs from Long *et al.* (1995);
- Effects Range-Median (ER-M) of 44.792 mg/kg for total PAHs from Long *et al.* (1995);
- Effects Range-Median (ER-M) of 9.6 mg/kg for HPAHs from Long *et al.* (1995);
- 1988 Puget Sound benthic community AET of:
    - 13 mg/kg for total LPAHs
    - 69 mg/kg for total HPAHs;
- 1988 Puget Sound amphipod AET of:
    - 24 mg/kg for total LPAHs;
    - 69 mg/kg for total HPAHs;
- 1988 Puget Sound oyster larvae AET of:
    - 5.2 mg/kg for total LPAHs;
    - 17 mg/kg for total HPAHs;
- San Francisco Bay:
    - 0.87 mg/kg based on bivalve larvae AET for total PAHs;
    - 15 mg/kg for amphipod bioassay AET for total PAHs;
- Mississippi Sound:
    - >205 mg/kg based on amphipod bioassay AET for total PAHs;
    - 99.4 mg/kg based on mysid bioassay AET for total PAHs;

Literature-based benchmark concentrations for PAHs suggest effect concentrations are highly variable, encompassing 2 or more orders-of-magnitude. This uncertainty relates to the variation of the source type of PAHs, sediment type, the physical environmental conditions of the water bodies studied, and/or a range of different organisms tested. The majority of literature studies were either from sites having different source types of PAHs, co-occurring contaminants (non-PAH), or different environmental settings that could affect the bioavailability of PAHs and their toxicity. Given the uncertainty relating to source type, toxicity and bioavailability, benchmark criteria and concentration ranges were chosen for PAHs that include:

- For open water and intertidal mudflats/fringe marsh areas:
    - No injury = sediment concentrations < ER-L (tPAHs > 4.022 mg/kg );
    - Possible injury = ER-M < sediment concentrations < ER-M HPAHs (tPAHs > 4.022 mg/kg & HPAH < 9.6 mg/kg) and
    - Probable injury = sediment concentrations > ER-M (HPAHs _ 9.6 mg/kg).
- For oyster reefs:
    - No injury = sediment concentrations < oyster larvae AET (LPAHs < 5.2 mg/kg, **and** HPAHs < 17 mg/kg).
    - Probable injury = sediment concentrations >oyster larvae AET (LPAHs > 5.2 mg/kg, **or** HPAHs > 17 mg/kg).

Figure 3 depicts the locations within Lavaca Bay where sediment concentrations of total PAHs exceed the ER-L (4.022 mg/kg) and HPAHs ER-M (9.6 mg/kg) values. Figure 4 depicts the locations where the oyster larvae AET (LPAHs > 5.2 mg/kg and/or HPAHs > 17 mg/kg) is exceeded. The acres of bay sediments exceeding benchmark concentrations, by habitat type, include:

- Open water habitats:
  - tPAHs in sediment > ER-L: 174.45 acres
  - HPAHs in sediment > ER-M: 117.40 acres
- Fringe marsh habitats (with adjacent mudflats):
  - tPAHs in sediment > ER-L: 10.58 acres
  - HPAHs in sediment > ER-M: 17.02 acres
- Oyster Reefs:
  - PAHs in sediment > Oyster Larvae AET: 7.08 acres

### 3.1.3 Co-occurring Mercury and PAHs

For estimating potential injury, effects that may result from elevated concentrations of co-occurring mercury and PAH concentrations were considered. For RWC purposes, an assessment was made to determine the locations where both mercury and PAHs concurrently exceed their respective benchmark concentrations. Because a range of potential effects concentrations was considered for mercury and total PAHs, when considered simultaneously, there are a series of combinations within the various habitats that must be considered independently. For open water, intertidal mudflats and fringe marsh habitats, the possible combinations of co-occurring chemicals concentrations considered include:

| Mercury[a] | | PAHs[b] |
|---|---|---|
| – Mercury < ER-M | & | tPAH ER-L<PAHs<HPAH ER-M |
| – Mercury < ER-M | & | HPAHs > ER-M |
| – ER-M < Mercury <AET | & | tPAHs < ER-L |
| – ER-M < Mercury <AET | & | tPAH ER-L<PAHs<HPAH ER-M |
| – ER-M < Mercury <AET | & | PAHs > HPAH ER-M |
| – Mercury > AET | & | tPAHs < ER-L |
| – Mercury > AET | & | tPAH ER-L<PAHs<HPAH ER-M |
| – Mercury > AET | & | HPAHs > ER-M |

[a]Mercury ER-M = 0.7 mg/kg, AET = 2.1 mg/kg.

[b]PAH ER-L =4.022 mg/kg; HPAH ER-M = 9.6 mg/kg.

and for oyster reefs:

| Mercury[c] | | PAHs[d] |
|---|---|---|
| – Mercury < AET | & | PAHs > AET |
| – Mercury > AET | & | PAHs < AET |
| – Mercury > AET | & | PAHs > AET |

[c]mercury oyster larvae AET = 0.59 mg/kg

[d]PAH oyster larvae AET is LPAHs = 5.2 mg/kg and/or HPAHs = 17 mg/kg.

Figure 5 depicts locations of bay sediments associated with co-occurring PAHs and mercury in soft bottom benthos (open water) habitats. Figure 6 depicts locations of bay sediments associated with co-occurring PAHs and mercury in intertidal mudflats/fringe marsh habitats.

Locations where mercury and PAHs co-occur in oyster reefs are depicted in Figure 7. The estimated acres for open water, intertidal mudflats and fringe marshes that are affected include:

| Co-occurring Chemicals | | Open Water | Fringe Marshes |
|---|---|---|---|
| Hg < ER-M | & ERL<PAHs<ERM | 137.22 | 5.67 |
| Hg < ER-M | & HPAHs > ERM | 66.30 | 3.75 |
| ER-M < Hg <AET | & tPAHs < ERL | 179.48 | 0.21 |
| ER-M < Hg <AET | & ERL<PAHs<ERM | 37.23 | 4.91 |
| ER-M < Hg <AET | & HPAHs > ERM | 47.24 | 13.22 |
| Hg > AET | & tPAHs < ERL | 6.35 | 0.0 |
| Hg > AET | & ERL<PAHs<ERM | 0.0 | 0.0 |
| Hg > AET | & HPAHs > ERM | 3.86 | 0.05 |

For oyster reefs, the estimated acres affected include:

| Co-occurring Chemicals | | | Oyster reefs |
|---|---|---|---|
| Mercury < AET | & | PAHs > AET | 3.11 |
| Mercury > AET | & | PAHs < AET | 14.95 |
| Mercury > AET | & | PAHs > AET | 3.97 |

### 3.1.4 Polychlorinated biphenyls (PCBs)

The Technical Memorandum: Bay System Stage 2B Data Assessment report presented a qualitative risk evaluation for PCBs detected in sediment. The purpose was to determine whether PCBs would contribute significantly to potential site risk and whether PCBs would be contaminants of concern for further quantitative evaluation. The analysis concluded that risk associated with sediment PCB contamination related to the Alcoa facility was quite low and did not warrant further evaluation or quantification. Furthermore, the locations at which sediment PCB concentrations were elevated, were also well within the areas impacted by mercury, PAHs or both. The response agencies concluded that any risk derived from PCBs would be addressed by actions that would be taken to reduce risk from the other contaminants.

The conclusion was based on a comparison of analytical data from samples in the area near the Alcoa Plant to sediment benchmark concentrations that include:

- 15 (of 111) samples exceed the ER-L (0.0227 mg/kg)
- 3 (of 111) samples exceed the ER-M (0.18 mg/kg)
- No samples exceeded AET developed for PCBs in Puget Sound.
- 10 (of 111) samples exceeded the Hudson River Threshold Effect Concentration (TEC) (40 ug/kg) and no samples exceeded the Mid-Range Effects Concentration (MEC) (400 ug/kg).

The potential for PCBs to pose significant risk was considered low based on a weight of evidence approach using the following:

(1) No sediment samples in the vicinity of the Alcoa Plant had total PCB concentrations that exceeded any of the AET values developed for Puget Sound (1 mg/kg for benthos, 1.1 mg/kg for oyster larvae, and 3.1 mg/kg for amphipod).

(2) No sediment samples exceeded the Hudson River Mid-range Effect Concentration (MEC = 400 ug/kg dw) in the vicinity of the Alcoa Plant.

(3) Only a limited number of samples, in localized areas exceeded the NOAA ER-M value. The areal extent of contamination exceeding the ER-M was restricted and co-located with elevated PAHs and mercury, and

(4) PCBs are generally not considered highly toxic to benthic fauna. There are limitations and uncertainties in the data from studies used to derive the sediment benchmarks. These uncertainties and their effect on deriving sediment benchmarks are discussed below.

Long *et al.* (1995) stated that the reliability and accuracy of the PCB ER-L and ER-M values was considered low compared to other hazardous substances for which these values have been developed (also, MacDonald, 1994). They determined that the incidence of effects associated with PCB concentrations greater than the ER-M value of 180 ug/kg was only 51 percent, compared with a greater than 80 percent incidence of effects for other organic compounds when the ER-M value is exceeded (Long *et al.* 1995). This indicates that increasing concentrations of PCBs at these low concentrations were not necessarily correlated with an increased incidence of toxic effects. This low correlation may be related to bioavailability, the presence of different combinations of toxic PCB congeners, and/or for some studies, the presence of co-occurring chemicals that may have resulted in PCBs actually contributing a relatively minor role in causing biological effects at these low concentrations (Long and Morgan, 1990). Fifteen of 111 samples exceed the ER-L (0.0227 mg/kg) and 3 of 111 samples exceed the ER-M (0.18 mg/kg). Locations where PCBs exceeded the ER-L and ER-M are depicted in Figure 8.

To summarize, although PCBs were detected in sediment, the trustees concluded that these chemicals did not contribute significantly to benthos injury. Where the low levels of PCBs were detected, the chemicals were co-located with areas with elevated concentrations of mercury and PAHs. The reasonable worst case analysis indicates that the small potential for injury associated with PCBs is encompassed by areas assessed as injured due to mercury and PAHs and therefore, will be compensated through restoration provided to address other losses. Thus, no further evaluation of potential injuries due to PCB contamination was conducted.

## 3.2 INJURY ESTIMATES IN SUPPORT OF HABITAT EQUIVALENCY ANALYSIS

For each area of habitat that is classified as injured using these benchmarks, an estimate is made of the extent of injury through an assessment of ecological service losses. Habitat Equivalency Analysis (HEA) is an accounting procedure used for scaling restoration options. However, a HEA requires some knowledge or estimates of the ecological service losses to evaluate the adequacy and appropriateness of proposed restoration options. For each habitat type, the amount of benthic community injury or service losses will vary according to the nature and extent of sediment contamination and remedial options implemented. This objective is accomplished by knowing the area of each habitat potentially injured by remedial activities or chemical contamination (presented in Section 4.0) and, for each area, determining the severity of injury. The severity of injury is used to develop estimates of the percent loss of benthos services that result from elevated concentrations of site-related chemicals.

### 3.2.1 Percent Loss of Services

An estimate of the percent loss of services was made for all areas where mercury or PAH concentrations exceeded selected benchmark concentrations. Additionally, all areas that are covered or dredged during remedial/removal activities through December 1999, are assumed to have been 100% injured. The predicted benthos service loss in each habitat type due to mercury or PAH sediment contamination was determined based on the mercury SQT, available scientific literature, and professional knowledge of Texas estuarine ecosystems. These estimates will be used as inputs to the HEA.

In estimating percent loss of ecological services for benthos in these areas, the following assumptions were made:

1) 100% losses apply to locations where chemical concentrations or remedial activities are sufficient to eliminate benthic populations and where no ecological services (decomposition, food, energy flow and cycling) are provided by benthos;

2) Sampling for the Mercury Reconnaissance (B2c), Sediment Quality Triad (B2g) and the Prey Item Study (B2e) identified and collected living benthic macroinvertebrates from habitats at all sampling locations. Because benthic organisms were found where contamination exists, injury to services provided by benthos in these areas is assumed to be less than 100%.

3) The benthic ecological service losses resulting from direct toxicity relate principally to a reduction in ecological services associated with decomposition, energy flow and nutrient cycling.

4) The ecological services provided by all resources within a habitat type at a particular location are assumed to total 100%.

Estimates of percent loss of ecological services were based on a weight-of-evidence approach and consensus judgment (of the Trustees and Alcoa) using results of available studies reported in the scientific literature, results of SQT, and knowledge of Texas estuarine ecosystems. For mercury, the percent loss of ecological services so identified and evidence used were as follows:

- The SQT found no observed decrease in survival for *Leptocheirus* spp., no apparent reduced growth for *Neanthes* spp, and no difference in the macroinvertebrate assemblages when compared to the reference area. The SQT was conducted over a mercury concentration range from 0.3 to 4.6 mg/kg, which encompasses the range of both the ER-M and AET. However, sub-lethal toxicological endpoints such as behavioral changes, loss of reproductive capacity, etc., were not measured in SQT. To be consistent with the RWC approach, a 10 % loss of benthos services was estimated for sediment Hg concentrations > the ER-M (0.71 mg/kg) but < the benthic AET, in open water, intertidal mudflats and fringe marsh habitats.
- A significant decrease in activity behavior of *Pontoporeia affinis* was noted at concentrations exceeding 2.15 to 3.35 mg/kg from sediment bioassays, as reported by Magnuson *et al.* (1976), as cited by Long and Morgan (1990). A 25% loss of services was calculated for concentrations > benthic AET (2.1 mg/kg).
- A 25% loss of services was estimated for mercury concentrations above the oyster larvae AET on oyster reefs. This injury value was consistent with the RWC approach and was based on best professional judgment.

For PAHs, the percent loss of services and identified evidence used are as follows:

- In open water and intertidal mudflats/fringe marshes, a 10% percent loss of services was determined for HPAH concentrations >ER-L and HPAH concentration < HPAH ER-M. This level of severity was established because:
    - The NOAA ER-L is based on sites with co-occurring chemicals. Additivity between mercury and PAHs was considered separately in this analysis.
    - The NOAA ER-L is lower than reported apparent effects thresholds (AETs) for PAHs, including the benthic AET (Puget Sound: LPAHs > 13 mg/kg and HPAHs > 69 mg/kg), amphipod AETs (Puget Sound: LPAHs > 24 mg/kg and HPAHs > 69mg/kg; San Francisco Bay: total PAHs >15 mg/kg; Mississippi Sound total PAHs > 205 mg/kg) and mysid AETs (Mississippi Sound total PAHs > 99.4 mg/kg).
- A 25% percent loss of services was estimated for sediment concentrations > HPAH ER-M. PAHs detected in Lavaca Bay sediments are predominately the higher molecular weight

PAHs. The NOAA HPAH ER-M (9.6 mg/kg) is lower than reported apparent effects thresholds (AETs) for PAHs, including the benthic AET (Puget Sound: HPAHs > 69 mg/kg), amphipod AETs (HPAHs > 69mg/kg; Mississippi Sound total PAHs > 205 mg/kg) and mysid AETs (Mississippi Sound total PAHs > 99.4 mg/kg).

- A 25% loss of services was estimated for total LPAHs (AET: 5.2 mg/kg) or total HPAH (AET: 17 mg/kg) concentrations above the oyster larvae AETs for sediments on oyster reefs.

For co-occurring PAHs and mercury:

- Estimates of percent loss of services for the individual constituents were assumed to be additive.

Based on available site-specific data, a greater uncertainty exists for estimating direct injury from PAHs because no site-specific studies were conducted to assess PAH toxicity. Therefore, it was conservatively determined that injury would begin where sediment concentrations exceed the lowest reported sediment benchmark criterion (i.e., the ER-L).

For locations where there are co-occurring elevated concentrations of mercury and PAHs, estimates for the percent loss of services were assigned to areas exceeding chemical benchmark criteria assuming additivity of effects for mercury and PAHs. Additivity was assumed since no data are available to suggest either synergistic or antagonistic toxicity between these chemicals to benthic invertebrates. Therefore, where co-occurring chemicals were present, the ranges used to assess the percent loss of services were:

| Mercury in Sediments | | PAHs in Sediments | % Service Losses |
|---|---|---|---|
| For open water and fringe marsh habitats: | | | |
| – Mercury < ER-M | & | ERL<PAHs<ERM | 10% |
| – Mercury < ER-M | & | PAHs > ERM | 25% |
| – ER-M < Mercury <AET | & | PAHs < ERL | 10% |
| – ER-M < Mercury <AET | & | ERL<PAHs<ERM | 20% |
| – Mercury > AET | & | PAHs < ERL | 25% |
| – ER-M < Mercury <AET | & | PAHs > ERM | 35% |
| – Mercury > AET | & | ERL<PAHs<ERM | 35% |
| – Mercury > AET | & | PAHs > ERM | 50% |
| and for oyster reef habitats: | | | |
| – Mercury < AET | & | PAHs > AET | 25% |
| – Mercury > AET | & | PAHs < AET | 25% |
| – Mercury > AET | & | PAHs > AET | 50% |

### 3.3 Restoration Scaling

The process of "scaling" a compensatory restoration action involves adjusting the size of the restoration action to ensure that the value of its resource and service gains over time equal the value of interim losses due to the hazardous substance release or response action. Compensatory restoration generally involves enhancing resources or providing replacement resources. In this case, estuarine open water habitat injuries will be compensated with estuarine marsh or oyster reef creation projects. Oyster reef habitat injuries will be compensated through creation of new oyster reef. Because the duration of the injury differs from the life span of the replacement action, equivalency should be calculated in terms of the present discounted value of service flows lost due to resource injuries and gained due to compensatory resource enhancement or creation.

The appropriate scaling approach depends on the type of available replacement resources and services relative to those injured. The two major approaches are the service-to-service or resource-to-resource approach and the valuation approach. The service-to-service approach requires that the lost and restored resources and services be the same type and quality, and of comparable value. In other words, the injured and compensatory resources must demonstrate similar capacity and opportunity to provide ecological services, and provide comparable human and ecosystem benefits.

Habitat Equivalency Analysis (HEA) is an accounting technique that provides a logical framework for scaling ecological restoration projects. The Trustees are using HEA in this case to scale ecological restoration projects and/or to evaluate restoration alternatives. In general, HEA functions to balance "debits" (injuries to habitats or resources) that have occurred against compensatory "credits" (resources or resource services provided by habitat restoration projects). The HEA-based scaling of restoration for all injury categories, including those to benthic resources, is to be documented in a separate technical memorandum.

## 4.0 SUMMARY AND CONCLUSIONS

An RWC analysis was conducted to determine the interim loss of ecological services due to the effects of elevated concentrations of mercury and PAHs on benthos. The RWC analysis used data collected during the remedial investigation studies to quantify injury to benthos based on sediment benchmark concentrations known or suspected to give rise to adverse effects on benthic populations.

The result of this RWC analysis provided an estimate of the total acres of each benthic habitat type (open water, fringe marsh and oyster reef) with potential for harm due to elevated concentrations of mercury, PAHs or a combination of these hazardous substances. A subsequent technical memorandum will employ HEA to scale the restoration necessary to offset losses of habitat and benthos services, as well as losses in other injury categories, through December 31, 1999. If necessary, additional analyses for remaining periods of injury will be conducted after decisions on the remedy for the Site are known.

## 5.0 REFERECES

Chapman, D., Nicholas Iadanza, And Tony Penn, 1998. *Calculating Resource Compensation: An Application Of The Service-To-Service Approach To The Blackbird Mine Hazardous Waste Site.* National Oceanic and Atmospheric Administration Damage Assessment and Restoration Program Technical Paper 97-1.

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Long, E.R. and L.G. Morgan, 1991. *The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program.* NOAA Technical Memorandum NOS OMA 52. August, 1991.

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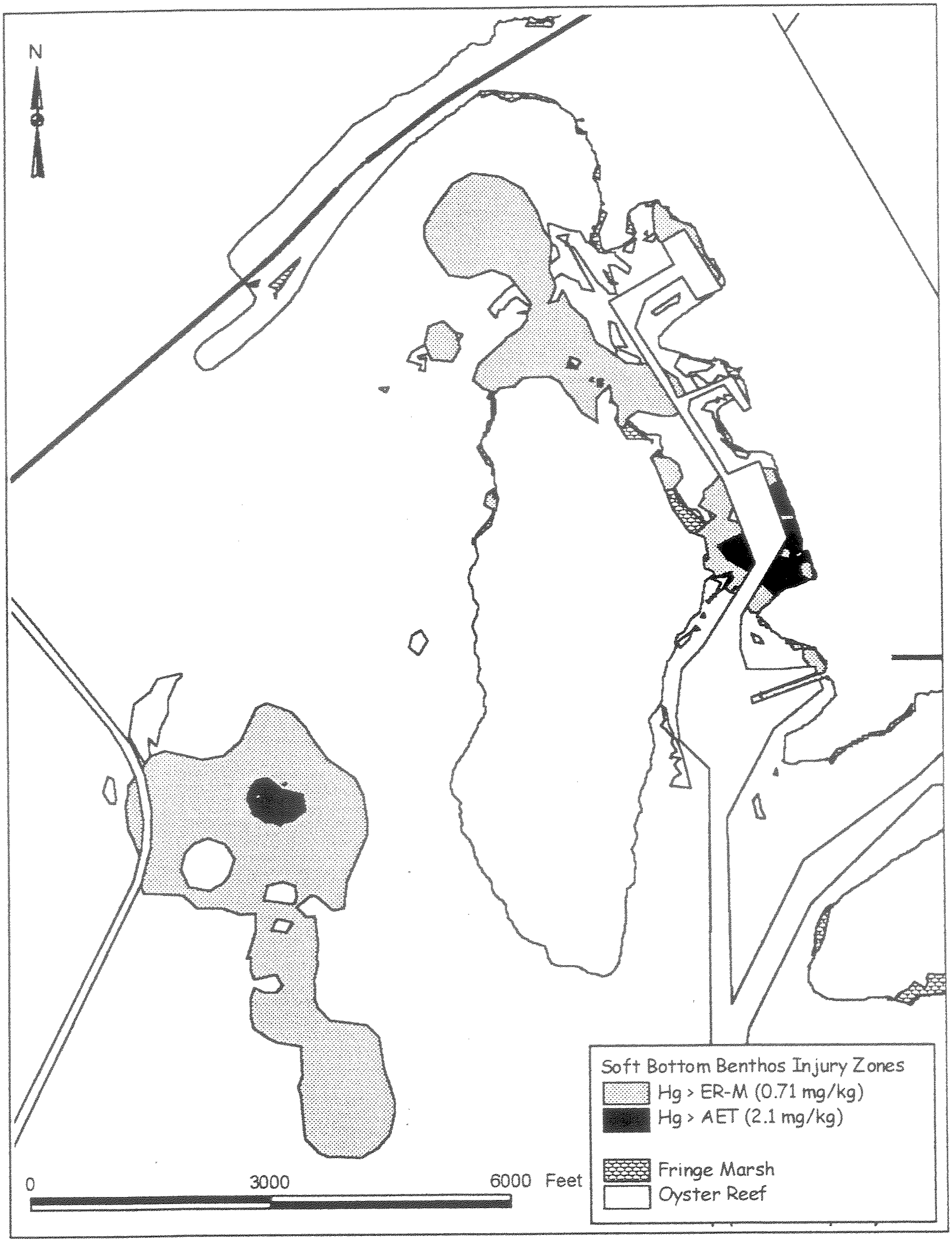


Figure 1 - Locations within Lavaca Bay where sediment Hg concentrations exceed the ER-M (0.71 mg/kg) and benthic AET (2.1 mg/kg) values in soft bottom, open water and fringe marsh habitats


Figure 2 - locations of oyster reef habitat within Lavaca Bay with sediment concentrations exceeding the oyster larvae AET (0.59 mg/kg) for mercury.

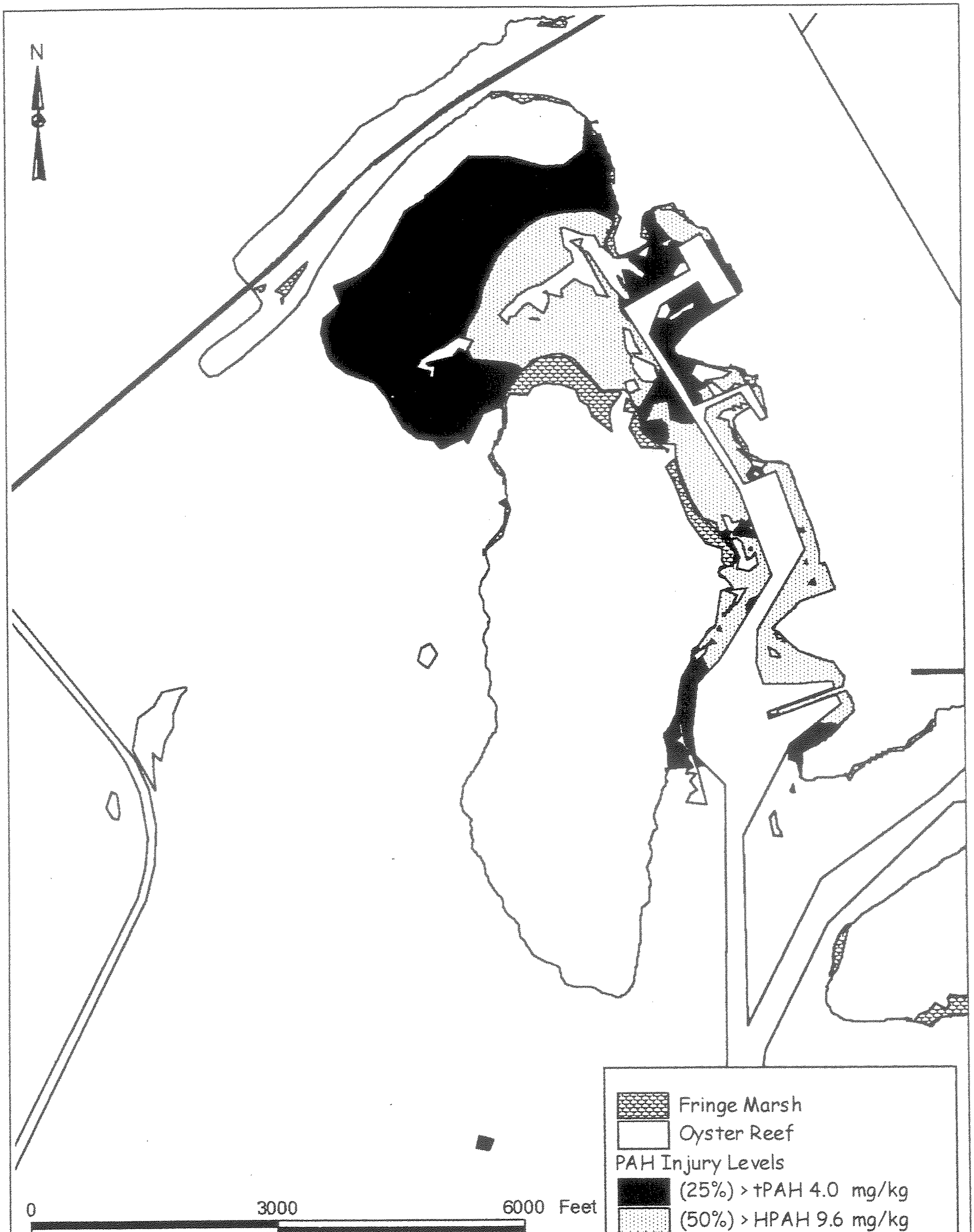


Figure 3 - locations within Lavaca Bay where sediment concentrations of total PAHs exceed the ER-L (4.022 mg/kg) and HPAHs ER-M (9.6 mg/kg) values.


Figure 4 - Locations within Lavaca Bay where sediment concentrations exceed the Oyster larvae LPAH or HPAH AET values - 5.2 & 17 mg/kg, respectively.

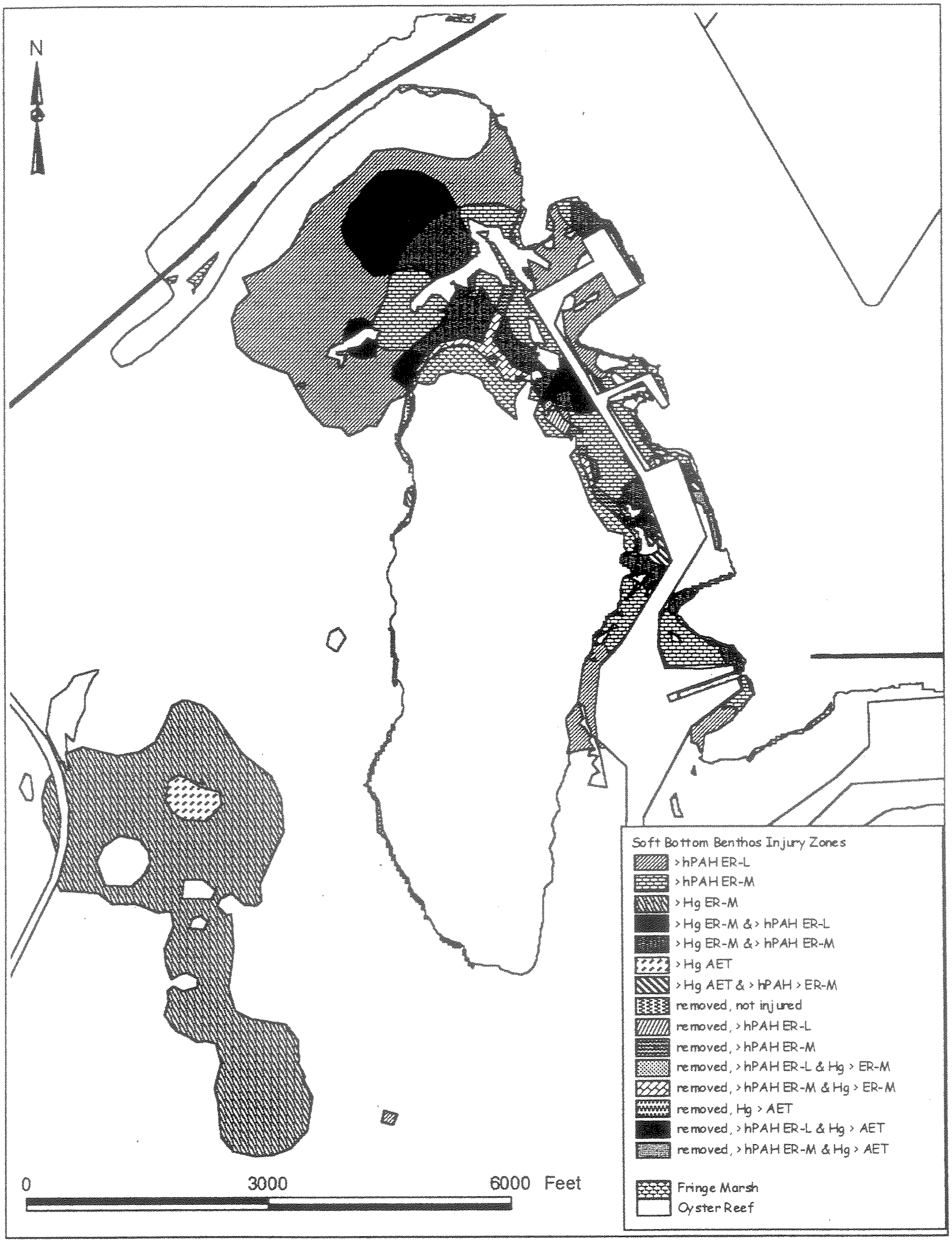


Figure 5 - Locations of bay sediments associated with co-occurring PAHs and mercury in soft bottom benthos (open water) habitats

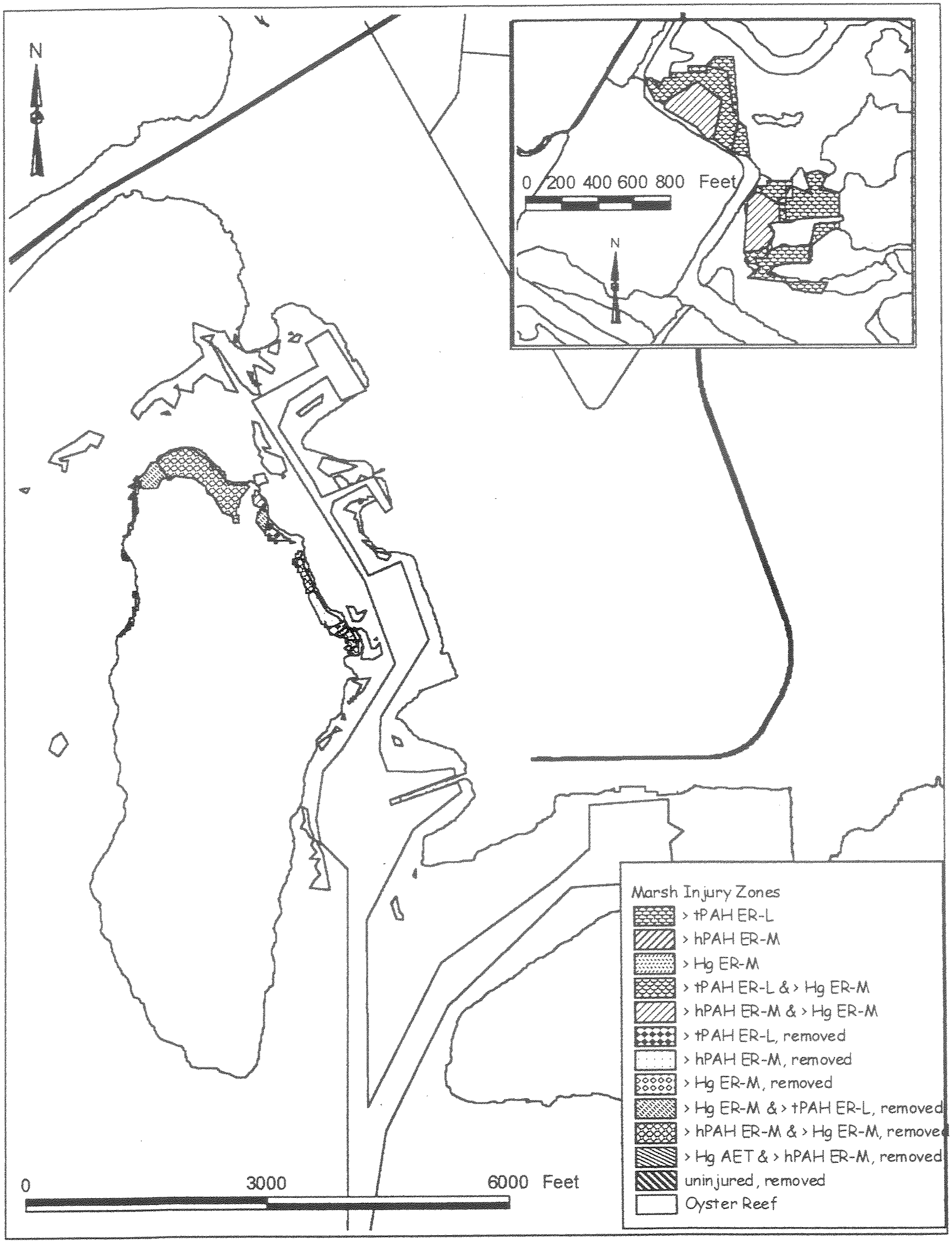


Figure 6 - Locations within Lavaca Bay where co-occurring PAHs and mercury in injuries exist in intertidal mudflats/fringe marsh habitats

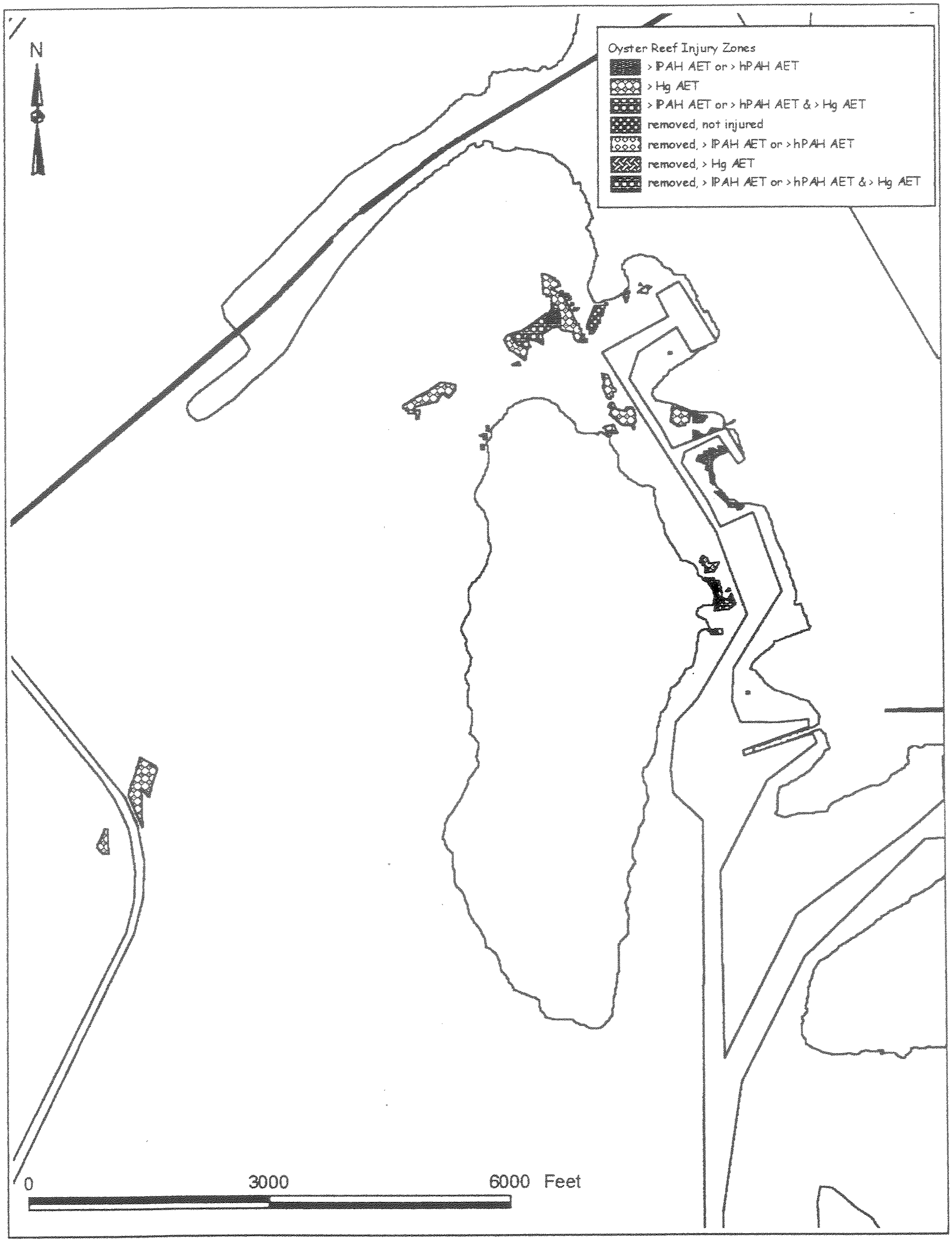


Figure 7 - Locations within Lavaca Bay where mercury and PAHs co-occur in oyster reefs


Figure 8 – Sediment PCB concentration compared to ER-L and ER-M benchmarks